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Vaño, R.; Lacalle, I.; Molina Moreno, B.; Palau Salvador, CE. (2021). Leveraging IoT and prediction techniques to monitor COVID-19 restrictions in port terminals. IEEE. 205-210.  
<https://doi.org/10.1109/WF-IoT51360.2021.9595919>



The final publication is available at

<https://doi.org/10.1109/WF-IoT51360.2021.9595919>

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# Leveraging IoT and prediction techniques to monitor COVID-19 restrictions in port terminals

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**Abstract**—Social distance restrictions have posed several challenges for the management of logistic nodes even in open spaces like a maritime port terminal. The Internet of Things combined with the simulation of supply chains provide the perfect breeding ground for devising innovative tools to help ports observe those restrictions. The objective of this paper is to devise such a tool based on research open results, proposing a clear architecture and use-case to be leveraged by maritime ports. Internet of Things techniques such as gathering heterogeneous data through a context broker, managing the Big Data generated and applying innovative models over that data set the foundations of the proposed system. The actual tool has been achieved as a result, together with a clear plan on future works that may build upon it.

**Keywords**—architecture, COVID-19, density, Internet of Things, monitoring, port terminal, real-time, supply chain

## I. INTRODUCTION

Apart from the devastating effects that COVID-19 is having on all civilization, its associated restrictions have generated challenges to multiple agents from many points of view in the logistic and transport sector. Ports are essential nodes in the multi-modal supply chain, being at the core of international exchange of goods and the movement of people; therefore, any deviation on their throughput has remarkable consequences in the global supply flow [1].

One of the restrictions that maritime ports have recently faced is to guarantee that the density of workers in specific areas (both indoors and outdoors) is limited to a certain threshold. This measure coupled with the reduction of activities redounds in a challenging scenario to be monitored in open environments like the terminal yard of maritime ports.

From another point of view, the Internet of Things (IoT) promises to be the solution for most monitoring requirements in maritime port services sector. Not only the ever-increasing volumes of information (sources say almost 80ZB of data coming from more than 40 billion devices by 2025 [2]), but also the minimization and affordability of the technology are making this approach the best candidate. Additionally, some traits of the IoT are the flexibility with regards to the usable data (many different sources) and to the services (configurability, computing capacity and scalability).

The objective of this paper is to propose a monitoring tool running over an IoT-based architecture for helping maritime ports address density of workers restriction in terminal areas. The goal is to leverage existing developments to devise a novel application inspired on a real case and scale it to a generic scenario for the benefit of the maritime community.

The paper is organized as follows: Section II provides the context of the proposal, i.e., how it was conceived, under which circumstances and for which purpose. Section III lays the technological foundation of the tools' architecture and a thorough description of its building blocks. Section IV evaluates the proposed and potential usage of the tool while Section V and VI reflect on future work and conclusions.

## II. CONTEXT

### A. COVID-19 restrictions in maritime port terminals

The main restrictions that port authorities have put in place are related to their outer interface at seaside. The most usual ones have been the port clearance, refusal of entry to ships, forcing vessels to spend a 14-day quarantine period at anchor before entering the port, conducting remote ship inspections and renewal of seafarers' certificates [3]. In other cases, the crew changes in the port have been limited [4] or Polymerase Chain Reaction (PCR) tests have been requested. However, this paper focuses on the application of social distancing [5] in the outdoors landside part of the port.

When analyzing social distance in indoor spaces of a port, port authorities, terminals and other entities apply the actions recommended by the governmental authorities, establishing measures to comply with the inter-personal distance [6]. In a closed scenario, occupancy control seems feasible. However, in terminal yards social distancing of 2 meters is not easy to control. Workers tend to move between areas aligned to their work shifts [7] and production needs. In that sense, *occupancy limit* has been proposed to be measured as workers per square meter [8].

### B. Growing impact of IoT as data gathering facility

The myriad of legacy systems in ports even Port Community Systems (PCS), paper-based documentation and procedures, among other, are converging to more centralized solutions like National Single Windows (NSW) to maximize the exploitation of available data [9]. In that context, the introduction of IoT systems to funnel those innovations into an all-encompassing solution is being boosted, both by private initiatives (port of Rotterdam [10], port of Hamburg [11]) and by public-funded actions (COREALIS [12], PortForward [13], DataPorts [14], SafePort [15], PIXEL [16]), in Europe and all over the world.

### C. The PIXEL project

PIXEL is a European Commission-funded (H2020 programme) action that has been running since May 2018 and that will provide its final results by summer 2021 [17]. It aims at being the first modular solution combining strong methodologies and smart technologies for small and medium port ecosystems enabling optimization of operations through

IoT while reducing environmental impact. The main offering of the project is a full-fledged IoT architecture and a series of services that are being validated in four European Ports (Bordeaux, Monfalcone, Thessaloniki and Piraeus). Those services aim at covering current gaps and challenges in the maritime sector such as energy demand prediction, traffic congestion forecasting, intermodal logistics harmonization and, specially, environmental impact reduction. At the very basis of the PIXEL architecture are the principles of flexibility, scalability, and adaptability to diverse IoT scenarios. In that context, due to the unexpected circumstances experienced since the advent of the pandemic in 2020, PIXEL decided to exercise that flexibility and to shift some efforts to run a pilot demonstration for helping maritime ports cope with adverse effects and COVID-19 associated restrictions. The objective was to leverage the work done in the architecture and the modelling of the logistic supply chain, equipment and agents intervening in the terminal of a maritime port.

#### D. Fit for advanced density monitoring tools

Ports have expressed growing interest in evaluating how the COVID-19 distancing measures could be introduced in the scheduling of port operations [18]. Drawing from this, a tool is devised that could allow the port manager to predict how many workers are expected to occupy one area of the terminal during a particular work shift. This piece of information may be useful for realizing at which shifts there would be a risk of violating the restrictions and to take proper measures consequently. If this plan (terminal schedule change) materializes, the activities in the terminal would last longer to operate the same amount of cargo, due to personnel unavailability. This effect could be monitored and observed as well by comparing the measured and predicted energy consumptions with and without COVID-19 restrictions scenarios. This way, the manager could realize which impacts in terms of productivity and energy efficiency would those measures have. From another perspective, it is known that the social distancing measures are contributing to reduce CO<sub>2</sub> emissions [19]. A tool allowing to monitor the CO<sub>2</sub> concentration in the air with the measures and then compare with values pre-COVID-19 may also help recognize the port's footprint to the environment.

#### E. Advantages over related works

Different techniques have been used in various cases for tracking social distance: LiDAR-based systems [20], auto-certifications of workers, sparse graphs of pedestrian dynamics [21] or cameras using Artificial Intelligence (AI) [22]. However, there has not been discovered a prognosis tool based on the logistics activity schedule to forecast a situation surpassing density of population threshold. Additionally, previous proposals cannot guarantee a non-invasive, plug-and-play deployment.

### III. PROPOSED ARCHITECTURE

The main purpose of this work is to design an architecture that relies on the principal technological concept of the research: The Internet of Things. The need of using an IoT based architecture is evident in a modern port, where data are collected from several sources (sensors, smart devices machinery, etc.) and not from classical static endpoints or centralized systems [23]. These heterogeneous

data must be collected and translated into a unified data repository to be ultimately exploited from a business perspective. IoT not only consists in retrieving data from a wide range of smart connected devices. The data should be retrieved in real-time and then managed by a component that could be a context broker [24]. The context broker manages the collected data performing different actions depending on its source.

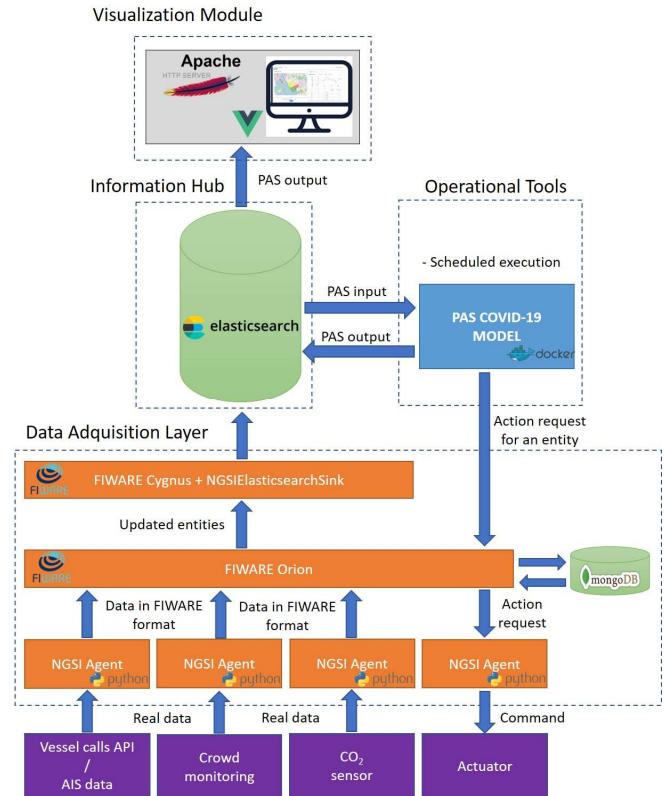


Fig. 1. Architecture proposed.

Moreover, an important feature of IoT systems is to control the behavior of singular smart devices called actuators. The context broker can send commands to an actuator to perform an action addressed to on-the-field users.

The architecture proposed in this paper (Fig. 1) draws from the work conducted in the PIXEL project, with *ad-hoc* adaptations and fine-tuning aimed at covering the requirements of the density of workers application. In that regard, PIXEL followed an approach based on globally accepted reference architectures for industrial IoT applications such as RAMI [25], IIRA [26] and IoT-A [27].

1) *Data provisioning:* Terminals in maritime ports might be in the position to acquire a wide variety of information that could be useful for monitoring the density of workers and mapping effects related to its restriction. For that reason, the architecture must consider the acquisition of heterogeneous data from dispersed sources:

- *CO<sub>2</sub> pollution:* Several studies have concluded that CO<sub>2</sub> emissions were highly reduced (~9%) in the lockdown-timespan of 2020 compared to the same period in 2019 [28][29]. In the context of a maritime port terminal, studying the evolution of CO<sub>2</sub> values (although those cannot be directly attributed to terminal operations only) might help characterize the

effects of restrictions in the environmental footprint. For obtaining these data, the use of sensors is preferred.

- *Vessel calls*: The essential information required to run the tool discussed. Captains of vessels must inform four working days in advance before arriving to a destination port via the so-called ANOA (Advanced Notices of Arrival) notification. From ports' side, knowing the number, nature, gross tonnage, the Expected Time of Arrival (ETA) and Departure (ETD) and other details of the ship, will allow to simulate the terminal operations during the span of a week, thus predicting the number of workers needed per area and time slot. This information may come in different ways, being the most usual one the connection to a remote server (web-HTTP, FTP, via APIs or others). However, there are other ways of gathering these data in case the calls would not be available. Here, the IoT comes again into play as the Automatic Identification System (AIS) data can be considered a data provider under the IoT comprehension. Using specifically-fledged equipment (transceivers and converters), AIS might be used to track the vessels in the near maritime area of a port to include them in the simulation for the tool.
- *Crowd monitoring*: The market offers several options for monitoring the people in a certain ground area of a city [30], being prominent the use of smartphone-based count analysis [31]. For the proposed case in this paper, this information will be useful to be compared with the predictions according to the supply chain and to foster port managers' capacity to quickly react in case restrictions were not met.

2) *Data concentration and accomodation*: Data are collected from different origins, so a component is needed to retrieve and then translate them into a unified data format, which in the architecture proposed will be based on the FIWARE Key Performance Indicator (KPI) datamodel [32]. This component is called *NGSI Agent* and it is the only one which establishes direct communications with the physical devices. In addition, the NGSI Agent (custom *python* script) will send a command to an actuator when receiving the order from the context broker. A context broker is a usual IoT component with the purpose of gathering real-time data from different sources into a centralized element.

The collected data aims to represent the status of the IoT system context in a concrete timestamp, for that reason, this information is named context information. Furthermore, it facilitates the goal of working under uniform syntactic and semantic structures for all incoming data sources. The context broker allows to control and validate the format of the received information, so it can also be seen as a data quality control module. For the implementation, the selected technology is FIWARE Orion [33], the context broker of the FIWARE open source IoT platform [34] (which allows the system to be certified as Powered by FIWARE). Orion needs the installation of a MongoDB [35] database in order to store the context information. FIWARE Orion structures the context data in different entities that have a set of attributes and only persists the last value of the entities'

attributes. In addition, Orion supports a subscription based model where external elements can subscribe to changes in entities' attributes.

3) *Data storage* in the context broker only ensures persistence of the last piece of data received. Thus, an additional system is required to store and persist this historical information. The FIWARE platform provides two different methods (enablers) for persisting the context data: Short Time Historic (STH), which is focused on storing the received data in a short period of time (e.g., day, week) with the purpose of quick retrieval of these data in an aggregated form, and the Long Time Storage (LTS), which is the classical persistence of data in a database. For this kind of storage, the FIWARE platform provides a module based on Apache Flume: FIWARE Cygnus [36]. This module is in charge of translating the data from the Orion entities' datamodel to the selected database's storage format. For this purpose, Cygnus has an additional component for each supported database named Sink.

The PIXEL project provides a functional block in charge of centralizing all the data retrieved from the Data Acquisition Layer (DAL), homogenizing and storing them in a database capable of supporting big queries and scaling horizontally: the Information Hub (IH) [37]. It is designed to be high performant and scalable, and the data are stored to support long-term queries. Furthermore, the core of the IH is an Elasticsearch database, which provides comprehensive data flattening, easy-to-use programming interface and automated filtering capabilities. For that reason, it fits perfectly in the IoT based system proposed.

4) *Terminal supply chain simulation*: This paper proposes the use of a software that has been already developed by PIXEL. This program, known as Port Activity Scenarrio (PAS) [38][39], consists of several blocks that, put together, model the schedule and performance of terminal operations needed to effectively operate a vessel (load/unload) and the processes involved, including the time allocated, energy consumed, machinery used and personnel devoted to that purpose (see Fig. 2).

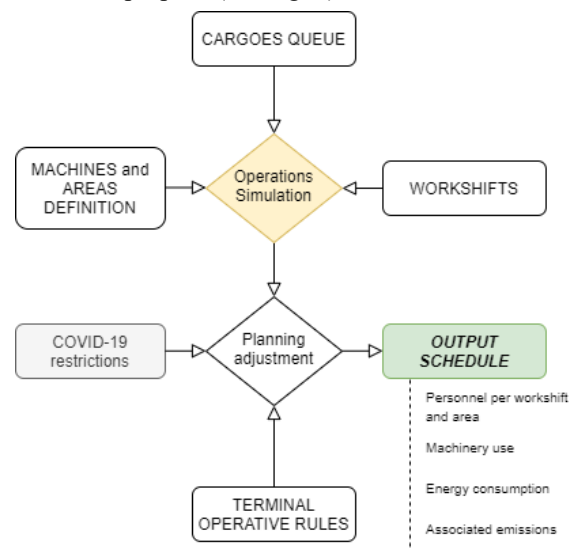


Fig. 2. Adaptation of the Port Activity Scenario for the proposed case.

For the utilization of this program in the architecture proposed in this work, some fine-tuning is needed. Embedded as a model in the application layer of the system, the PAS shall be enhanced to include the COVID-19 restrictions in its calculations to obtain a simulation and to allow the monitoring of the density of workers per area and per hour.

The procedure to be followed is to create such constraints and include them in the supply chain definition of the operations of the port in which the tool wishes to be deployed. For doing so, the PAS configuration allows to define a maximum number of workers per area, process and machine used in the terminal. This way, given a daily/weekly vessel plan, the supply chain will be calculated (i) as per usual schedule, based on terminal operative and priorities, (ii) considering those limitations, resulting in a specific schedule that will differ from the regular one.

Technologically, the PAS model is composed of various custom *python* scripts that interact among them to simulate the terminal schedule. For the integration, Docker [40] is used to containerize the application, facilitating the deployment within the architecture schema.

5) *Model execution and visualization.* At this moment all the components of the architecture have been described except for the visualization module. The Data Acquisition Layer should be working continuously, retrieving the data from the different sources and storing it in the Information Hub, being ready for the PAS execution. However, a component is needed for managing the execution of the core module of the architecture: the PAS model. Furthermore, this component has to indicate to the PAS the location of the of the input data needed for running the program and the execution frequency.

The PIXEL platform bases its operation on the developed orchestration component: the Operational Tools (OT) [41]. It intends to be a useful tool for the system

administrator for scheduling the execution of the models (such as the PAS) developed during the PIXEL project.

The results of the PAS execution must be observed in a user-friendly interface (UI), so the development of a visualization module is mandatory. One of the aims of this work is to use open source tools, for that reason the UI module has been developed using Vue.js [42], a lightweight and progressive framework for building user interfaces, together with a web components library called Element [43]. In addition, the javascript library Leaflet [44] combined with the open maps data from OpenStreetMap [45] have been used for creating the map module of the UI and the line charts of the UI have been drawn using the javascript library Apache Echarts [46]. Finally, the UI module retrieves the PAS output data needed for the visualizations using the Information Hub REST API.

In conclusion, the development of a Vue.js project results in a web page with the classical components: HTML, *javascript*, *CSS* and additional static files like images. For that reason, the open-source, secure, efficient and extensible Apache HTTP web server [47] has been chosen for hosting the user interface.

#### IV. USABILITY OVERVIEW

Apart from the conceptual description and the devisal of the architecture, the authors of this paper have already developed a human-machine interface (HMI) for port managers to use such a technological tool. Hereafter, the flow of actions to use this tool is depicted, establishing the basis for the forthcoming deployment in real European ports.

After consulting to various ports for the forecasted usability of such a tool, some port managers expect the visualization to showcase a map with the areas of the port representing the density of workers in a timeframe (typically: per hour). This way, the end user in the port will recognize how the operations have been re-scheduled

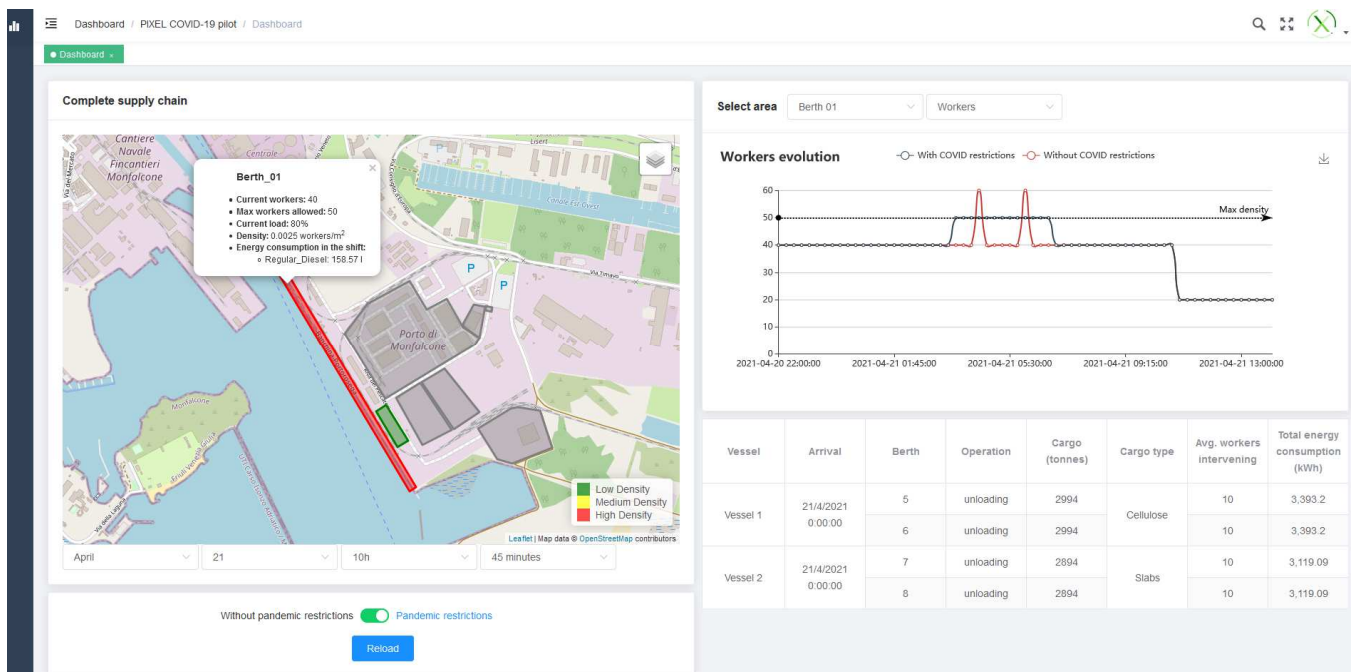


Fig 3. Dashboard proposed for the solution: including: (i) a view of port terminal areas in a map, detailing the workers' occupancy, (ii) a multi-line graph to monitor the evolution in time of such density, energy consumption (in kWh) and CO<sub>2</sub> emissions per area (assuming with/without pandemic restrictions) and (iii) an informative table providing estimations associated to each vessel to be operated.

through the PAS to meet the density limitations, while observing the evolution during the week and being able to compare with a non-pandemic scenario.

This visualization lets the user advance in a time bar to check the evolution of those parameters during the shifts. The interface also allows to see the results aggregated, per vessel and with/without pandemic constraints.

To provide a more proper *look and feel*, the designed screen displays the surface of the areas in different colors depending on the likelihood of surpassing thresholds of restrictions in each hour shift. Additionally, a multi-line graph has been included to facilitate the following: (i) analyzing and comparing the total number of workers that are operating in a certain area considering both scenarios, (ii) observing the deviation on energy consumption (in kWh) and (iii) tracking the CO<sub>2</sub> emissions associated to the operations in either case. Finally, a table is included with the information of all the vessel handlings being carried at the terminal in the analyzed period.

These data can be actioned through by the port via: (a) changes in shift plans for personnel and machinery so that the work will be redefined to minimize social aggregation at different areas of the port, therefore decreasing contact and virus spread among workers and (b) make use of the IoT system for immediate actuation through buzzers and lighting to warn the operators in the terminal about potential breaches of restrictions compliance. The scope of the architecture is to provide the technological baseline. Naturally, any action to be taken will be up to the competent authority to decide upon.

## V. FUTURE WORK AND RESEARCH LINES

The work proposed in this paper consists of a conceptual technological design accompanied by an available visualization interface. The whole system is compliant with the requirements obtained from the ports to solve a need uncovered by the state of the art. However, it is still a working scenario with plenty of potential additions and future research lines.

First, the main proposed continuation is the actual validation (as *proof-of-concept*) in a real port. Within the scope of the PIXEL project, the Port of Monfalcone expects to use the tool before the end of 2021.

Second, a lot of potential is envisaged by inserting added-value technologies atop the proposed architecture. For instance, the incorporation of Artificial Intelligence (AI) for forecasting deviations in the density restriction compliance making use of available open framework and libraries. AI might be used here as well for other objectives such as pattern recognition, long-term planning, or cross-relation discoveries.

From another perspective, the system would be much more powerful with the inclusion of additional, different data sources. One example may be cameras to record the actual density of workers per area, potentially leveraging satellite data as well. Other IoT-related sources such as RFID tags or wearables may help fine-tuning the control of social distance in maritime ports. These might also open a whole new range of actuation possibilities, e.g., denying access to certain areas. However, all the previous poses remarkable challenges

not only technically but also legally and ethically, which would deserve a separate analysis.

Finally, a clear addition to the proposed tool would be the aggregation of functionalities to cover the control of other type of measures, like the crew change at arrival and departure, as remarked in Section II.A.

## VI. CONCLUSIONS

This paper has come up with a technological proposal based on an IoT architecture for helping maritime ports cope with some challenges associated to COVID-19 restrictions. Using IoT techniques building on available results from open research already seems a viable solution with clear potential from various perspectives. This field of work promises to be further explored in the future as new sources and services will be required.

## ACKNOWLEDGMENT

This work is part of the PIXEL project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 769355.

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